Probing Low-Energy Solar Neutrinos with XENONnT via Electron Recoils

Yue Ma (yuema@physics.ucsd.edu) on behalf of the XENONnT Collaboration

RareLabs, Physics Department, UC San Diego

Neutrino 2026: XXXII International Conference on Neutrino Physics and Astrophysics

The XENONnT Experiment

The XENONnT experiment [1] at **LNGS**, Italy, operates **8.6 tonnes of liquid xenon (LXe)** in a dual-phase Time Projection Chamber (TPC) to search for dark matter and rare interactions, including solar neutrinos.

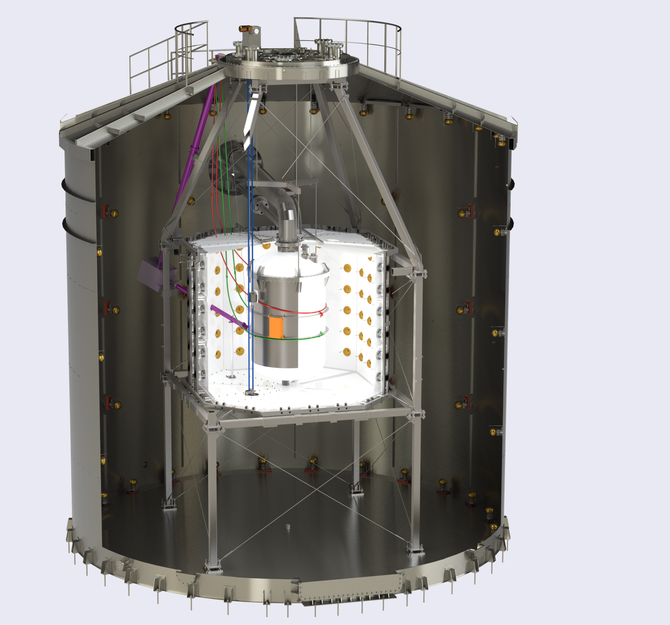


Figure: XENONnT detector. The inner TPC is surrounded by a neutron veto (white) and muon veto (grey) in a 700-tonne water tank.

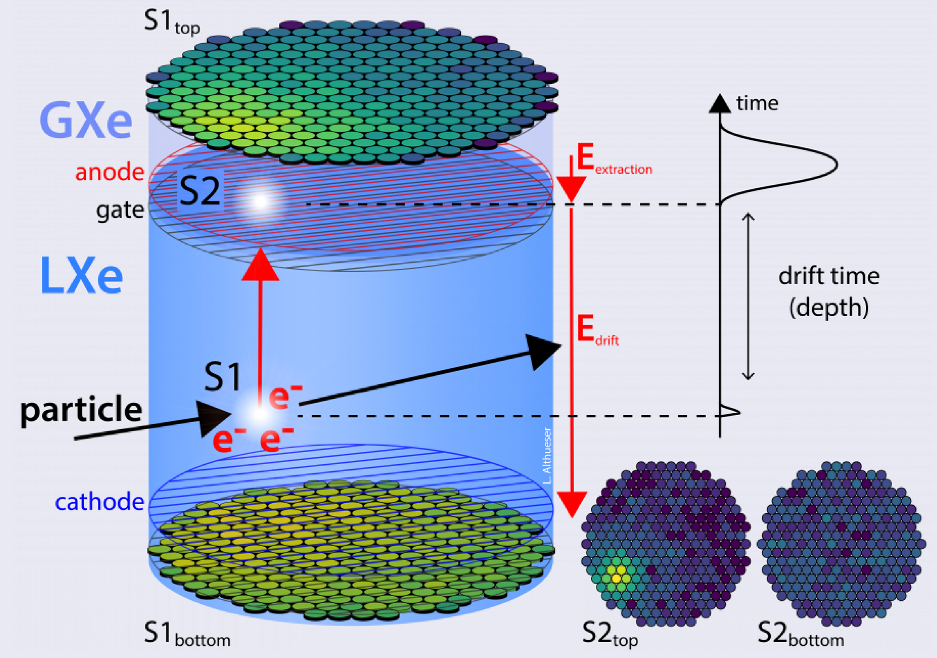
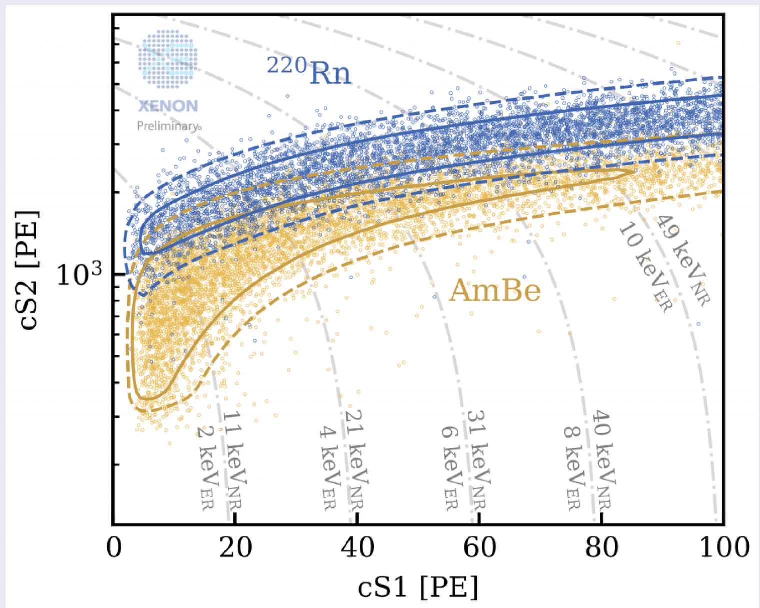


Figure: Signal generation in a LXe TPC. A particle interaction produces prompt scintillation (S1) and ionization electrons drifted to the gas phase, generating a delayed electroluminescence signal (S2).

- **Electronic Recoils (ER)**: interactions with shell electrons (β, γ, ν-e scattering)
- **Nuclear Recoils (NR)**: interactions with the Xe nucleus (WIMPs, neutrons, CEνNS)



Solar *pp* Neutrinos

pp fusion reaction ($p + p \to d + e^+ + \nu_e$): Produces **highest-flux** and **lowest-energy** (endpoint 420 keV) solar neutrinos – detectable in XENONnT via neutrino–electron elastic scattering (ER channel) with an $\mathcal{O}(1\,\mathrm{keV})$ threshold and $<$ **20 events/(t·yr·keV)** background level in (1, 30) keV [2].

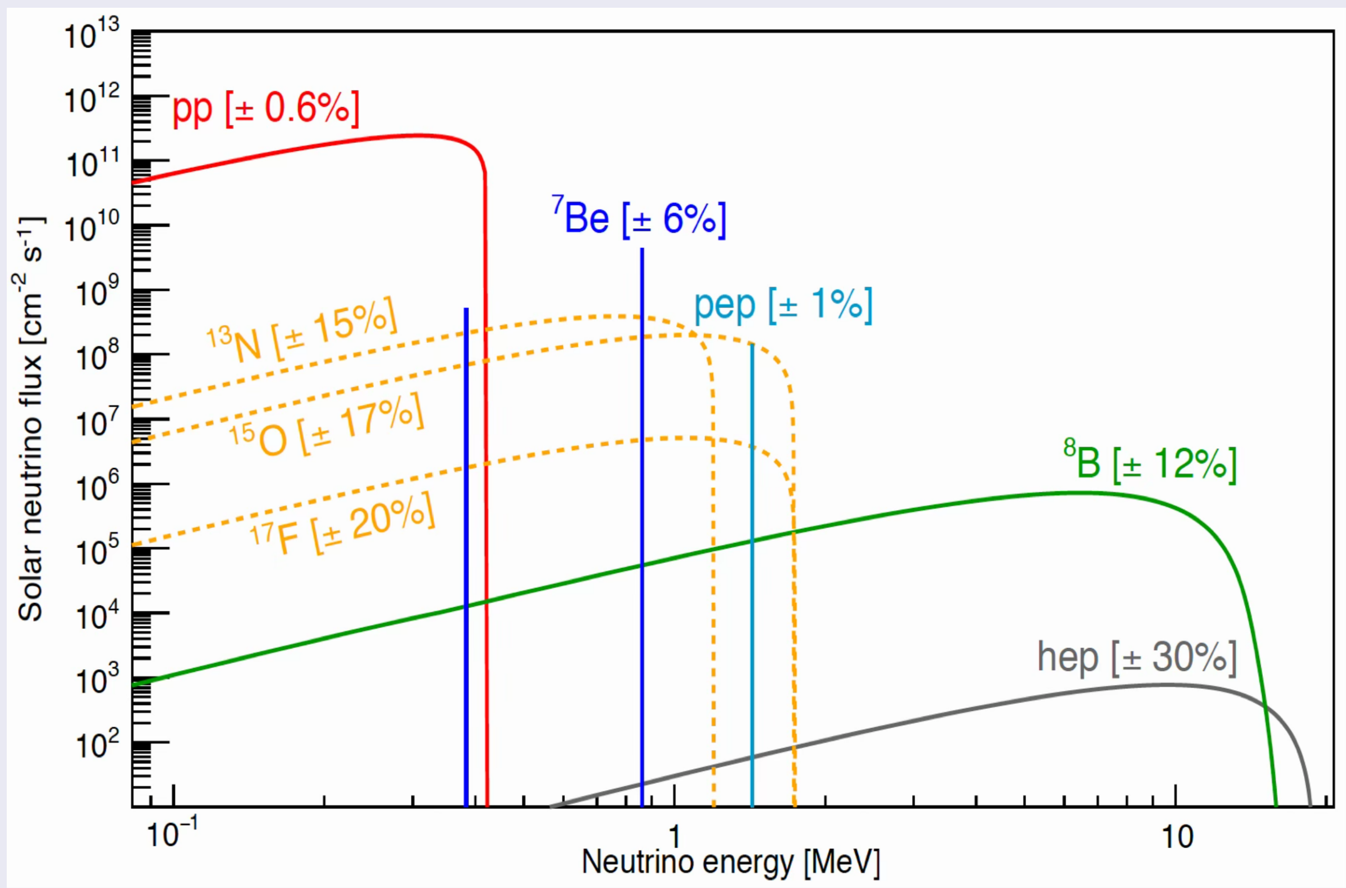
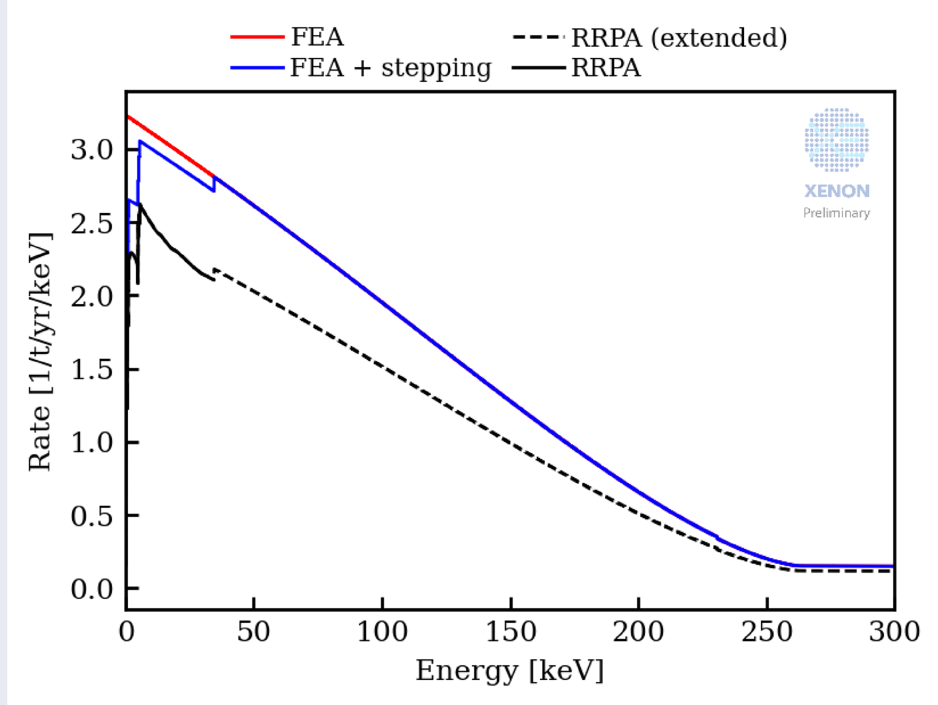


Figure: Solar neutrino flux as a function of energy [3]. The *pp* channel (red) dominates in flux with the lowest energy endpoint at 420 keV, falling within XENONnT's ER detection window.

Signal Model of the Solar *pp* Neutrinos in XENONnT

Signal Model: Solar *pp* neutrino interactions are modeled via neutrino–electron elastic scattering. Two cross-section models are considered:

- **Stepping** (Nominal): Free electron approximation with atomic binding energy correction
- **RRPA**: Relativistic Random Phase Approximation [4]



Background Model

Noble gas backgrounds

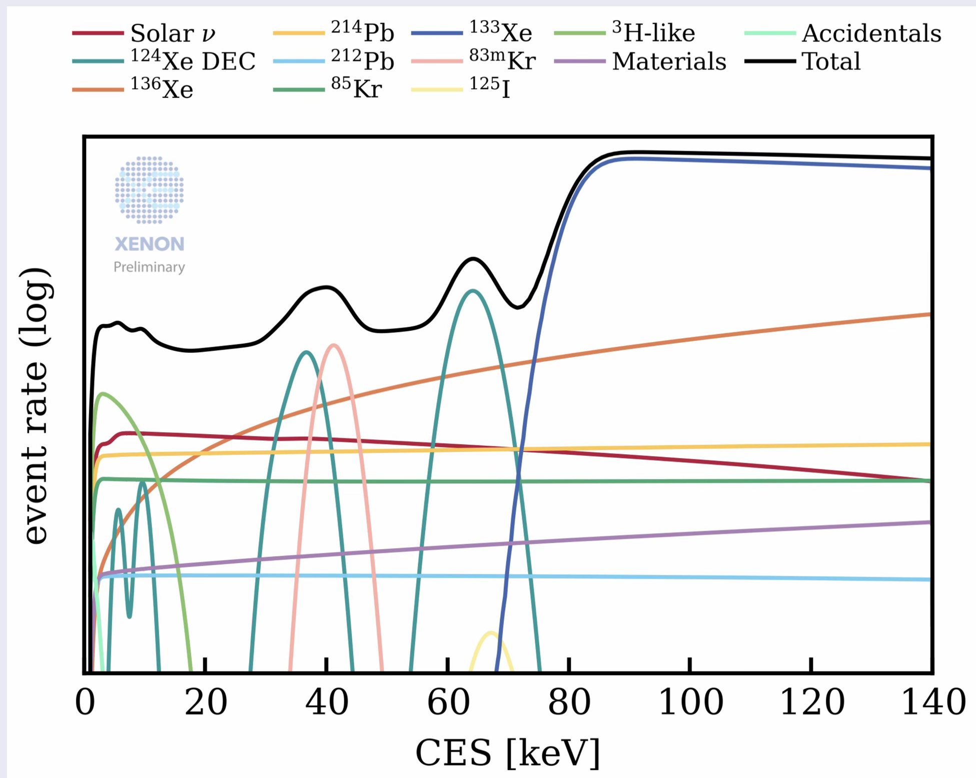
- $^{222}Rn/^{220}Rn$: decay daughters of detector materials; dominant ER background
- ^{85}Kr: from ^{nat}Kr in the xenon inventory

Xenon isotopes

- $^{136}Xe/^{124}Xe/^{133}Xe$

Materials Background

- From radioactive materials in detector surface

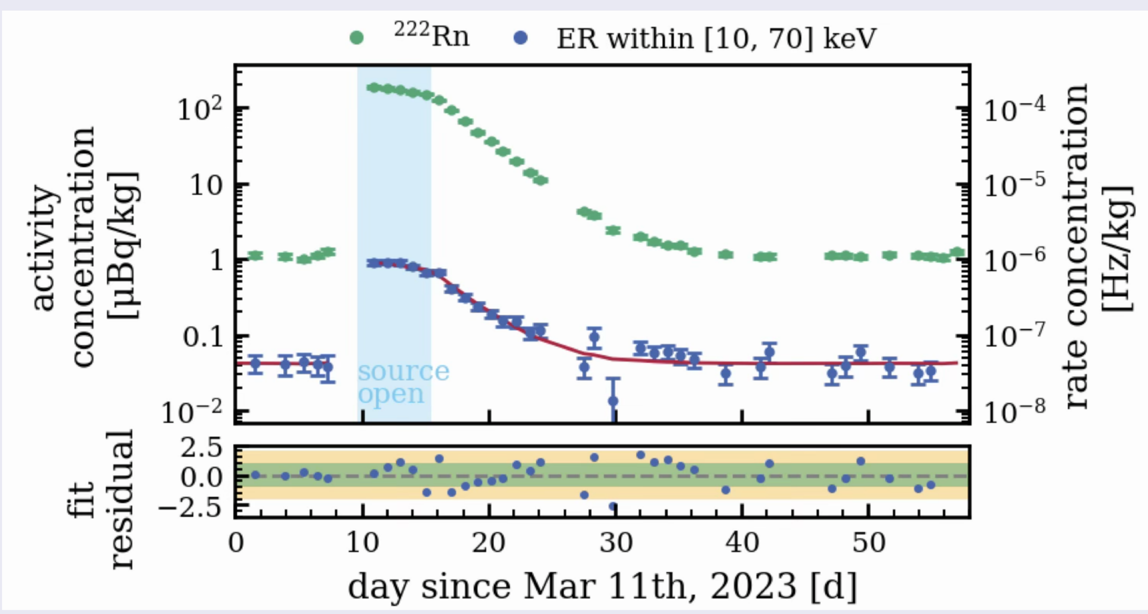


Other backgrounds: ^{3}H-like, ^{83m}Kr, ^{125}I, Accidental Coincidences

Constraining the Radon Background

^{214}Pb (β decay daughter of ^{222}Rn) is the **dominant background** in the LowER channel. A two-step strategy is employed:

Step 1 — Removal: A dedicated online radon distillation system continuously suppresses ^{222}Rn to the level of $\sim 1.0\,\mu\mathrm{Bq/kg}$.



Green: ^{222}Rn α rate
Blue: ER event rate within [10, 70] keV (blue) during the ^{222}Rn calibration campaign.
Red curve: the fitted ^{214}Pb prediction.

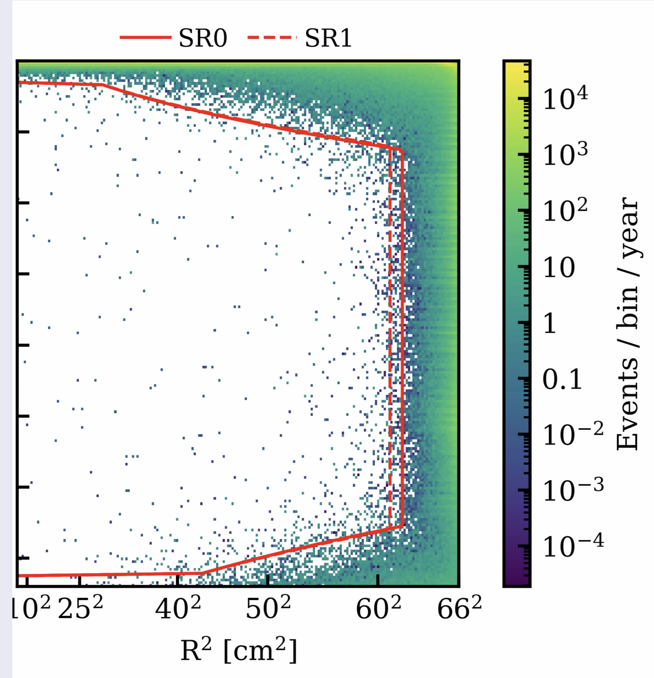
Step 2 — Estimation: ^{214}Pb is a β-decay daughter of ^{222}Rn; its activity is directly linked to the ^{222}Rn α decays, with a **plate-out correction** (decayed ions drifting to detector walls, reducing ^{214}Pb activity). A dedicated ^{222}Rn source was injected during Science Run 1b (SR1b), elevating the ER rate by $>100\times$. The $^{214}Pb/^{222}Rn$ activity ratio is extracted via a fit to the correlated ^{222}Rn α and ^{214}Pb β rates:

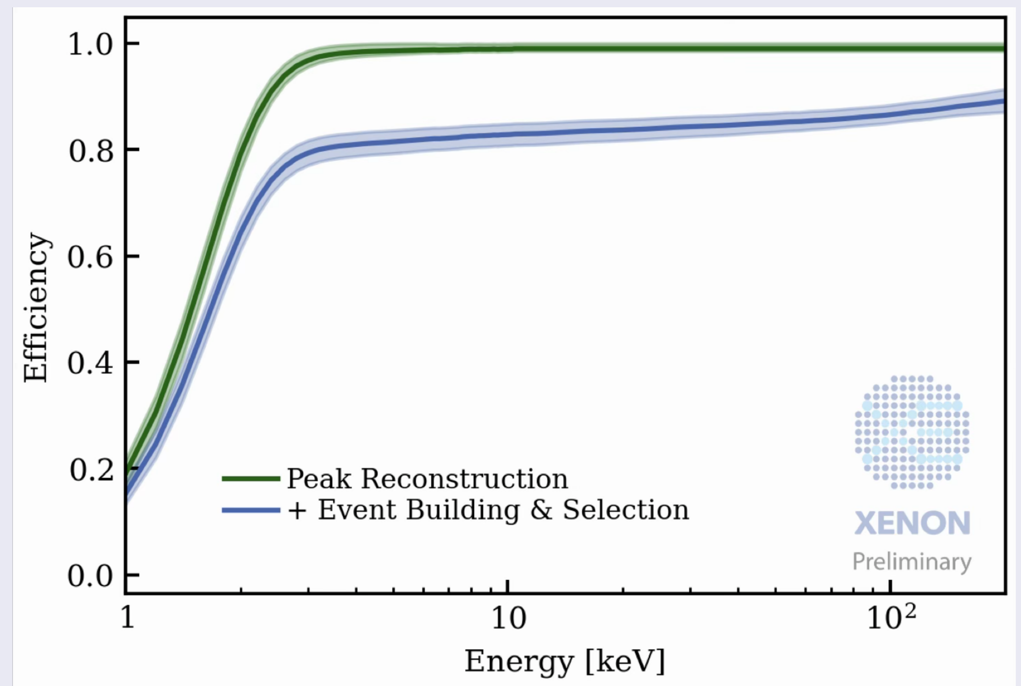
$$R_{\mathrm{ER,total}} = m \cdot R_{^{222}\mathrm{Rn},\,\alpha} + \text{constant ER background}$$

yielding a 5% precision in ^{214}Pb estimation.

Data Selection & Efficiency

Livetime: 214.4 days in total with Science Run 0 (SR0) and 1b (SR1b).
Left: Fiducial Volume (FV): optimized in (R^2, z) space to maximize signal-to-background ratio, yielding a fiducial mass of **4.13±0.12 t (SR0)** and **4.24±0.13 t (SR1b)**.





Right: The **total efficiency** accounts for peak reconstruction, event building, and data quality selections, evaluated at $\approx$ **1%** percision using a data-driven method with various calibration data.

Projection & Outlook

Sensitivity Projection (Preliminary): $\approx 4\sigma$ discovery power

Outlook: LXe TPCs are a new platform for real-time solar neutrino spectroscopy, with sensitivity to P_{ee} and $\sin^2\theta_W$ at the **lowest momentum transfer** ($\mathcal{O}(10^{-4}\,\mathrm{GeV})$) achieved to date. Next-generation experiments such as XLZD will push toward sub-percent precision on the *pp* flux.

Results coming soon!

References

[1] Aprile, E., et al. "The XENONnT dark matter experiment." The European Physical Journal C 84.8 (2024): 784.
[2] Aprile, E., et al. "Search for new physics in electronic recoil data from XENONnT." Physical Review Letters 129.16 (2022): 161805.
[3] "Comprehensive measurement of pp-chain solar neutrinos." Nature 562, no. 7728 (2018): 505-510.
[4] Chen, Jiunn-Wei, et al. "Low-energy electronic recoil in xenon detectors by solar neutrinos." Physics Letters B 774 (2017): 656-661.